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NaI(Tl) detectors modeling in MCNP-X and Gate/Geant4 codes

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ABSTRACT

NaI (Tl) detectors are widely used in gamma-ray densitometry, but their modeling in Monte Carlo codes, such as MCNP-X and Gate/Geant4, needs a lot of work and does not yield comparable results with experimental arrangements, possibly due to non-simulated physical phenomena, such as light transport within the scintillator. Therefore, it is necessary a methodology that positively impacts the results of the simulations while maintaining the real dimensions of the detectors and other objects to allow validating a modeling that matches up with the experimental arrangement. Thus, the objective of this paper is to present the studies conducted with the MCNP-X and Gate/Geant4 codes, in which the comparisons of their results were satisfactory, showing that both can be used for the same purposes.

1. INTRODUCTION

The Monte-Carlo technique is widely used within the radiation field, in medical and industrial researches, radiation protection and nuclear facilities, for example. It is an excellent tool for radiation transport that helps project development since it facilitates the construction of geometries, use of varied detectors and energies, thus eliminating problems with detector availability, radiation sources, and experimental tests, since there is no need of an experimental arrangement.

However, a wrong modeling can bring problems to the project, increasing unforeseen costs, [illegible] r hand, a proper modeling, which ensures the complete matching up of computational with experimental results, is extremely important. Thus, the objective of this paper is to present a methodology for detector modeling in MCNP-X (Monte-Carlo N-Particle eXtended) [1] and Gate (Geant4 application) codes[2].

The methodology is simple and can be applied in several studies, particularly those that focus volume fraction determination in pipelines.

Such methodology was developed because of the great difficulty found to validate the modeling of a 1x1" NaI(Tl) detector, because the simulated results were very different from the experimental results. Initially, the modeling was performed in MCNP-X, but, as the results were very different, we decided to use Gate for that modeling. The latter results also diverged from experimental and from those obtained by MCNP-X.

In face of those difficulties, we perceived the need for a new methodology meeting the following criteria:

- Simple to implement;
- That could be implemented in both codes in the same manner;
- And that brought the same results in both codes.
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2. EXPERIMENTAL ASSEMBLY

A 1x1" NaI detector was used together with a PVC (polyvinyl chloride) support. This support is important to ensure that all the sources will be at the same position, at the same distance from the detector (10 cm) and in its axial center. The modeling demands obtaining spectra from three different sources. The assembly used in the experiment is shown in Fig. 1a. Fig.1b shows the place where the source is positioned, opposite from the detector.

(a) (b)

Figure 1: Experimental assembly.

In order to be as faithful as possible to the experimental arrangement, the geometry constructed in MCNP-X and Gate takes into account the structure of the detector and the support, and also, of the source pellet. The detector is the same used by SALGADO et al. [3].

3. OBTAINING SPECTRA

First, it was necessary to know the influence of the noises from the environment where the experiment was conducted. To this end, two 8-hour measurements were taken to obtain the background spectrum (BG), one with and the other without a lead shield around the detector.

Then, the spectra were obtained using three different sources (241Am, 133Ba and 137Cs), because this is the only way to obtain the parameters 'a', 'b' and 'c' for the MCNP-X's GEB (Gaussian Energy Broadening) command, calculated from Eq. (1) [1].

$$FWHM = a + b\sqrt{E + cE^2} \tag{1}$$

Fig. 2, Fig. 3 and Fig.4 show the spectra of the aforementioned sources. It is possible to observe that BG does not significantly influence the counts, mainly in the region of interest which is the photopeak.

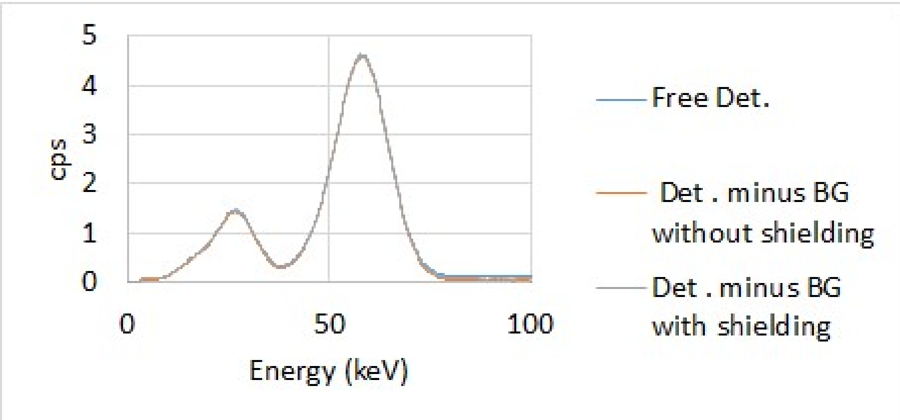

Figure 2: Am-241 spectrum.

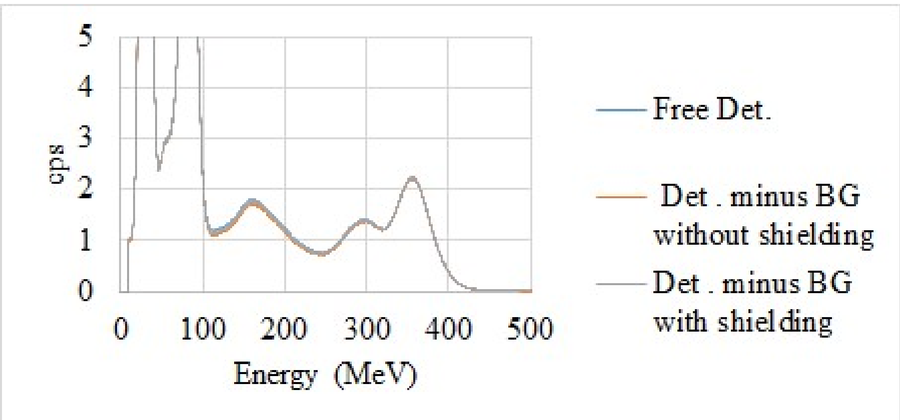

Figure 3: Ba-133 spectrum.

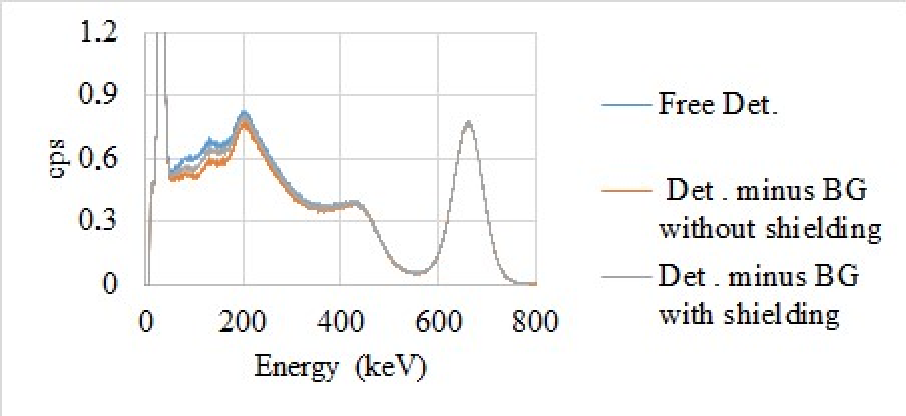

Figure 4: Cs-137 spectrum.

Fig.5a shows the curve of energy resolution, Eq. (2), and Fig. 5b the FWHM (*full width at half maximum*) curve as a function of the energy expressed by the function represented by Eq. (1), used to obtain the parameters (Table 1) to be used in MCNP-X's GEB command.

$$R = \frac{FWHM}{E_0} \tag{2}$$

Table 1: Values of parameters a, b and c.

a	b	c
-0.007760452595	0.09767721515	0.01564700514

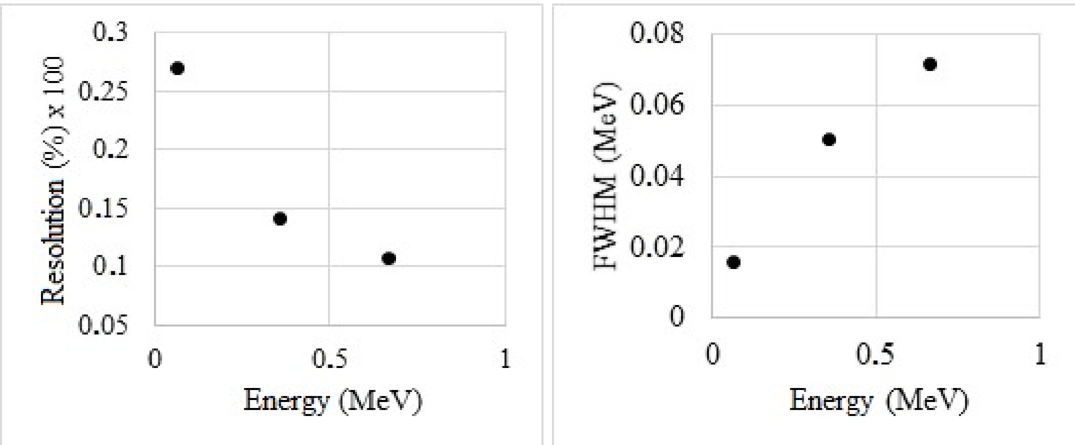

Figure 5: a) Energy resolution; b) FWHM.

4. Methodology

The new methodology consists in the normalization of the results obtained by MCNP-X (and Gate) followed by a denormalization by a standard value, which will be the same in all denormalizations for the same source.

Initially, the spectra obtained by simulation are normalized using the highest value of the photopeak, which we will call CPSs. We used the photopeak region because it is the region of interest. The experimental spectrum is then normalized, also by the photopeak's highest value, which we will call CPSe. To denormalize the simulated spectrum it is only necessary to multiply it by CPSe.

By using CPSe to denormalize we ensure that the region of interest of the simulated spectrum is as close as possible to the experimental, thus validating the simulated model.

4.1. How is this methodology applied to volume fraction studies?

The study of volume fractions consists in simulating several levels of fluid (water) inside a PVC pipe, as illustrated in Fig. 6. The first simulation is carried out with the pipe completely empty.

At the same time, the spectrum with the empty pipe is obtained experimentally. This experimental spectrum will be used as basis to obtain the standard value of CPSe. Nevertheless, a similar spectrum obtained by simulation, also with the empty pipe, is used to obtain CPSs.

The idea is to use the value of CPSs found for the empty pipe to normalize all spectra obtained by simulation (with variable volume fractions). Then, the value of CPSe is used to denormalize those spectra.

It is important to bear in mind that the values of CPSs and CPSe have to be the same for all simulated spectra. In this way, it is possible to ensure that the simulated spectra are as close as possible to the experimental spectra.

Finally, after denormalization, these spectra can be used for training the neural network for the detection of void fractions ([4], [5]).

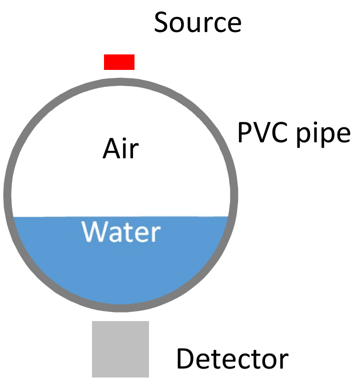

Figure 7: Assembly scheme for void fraction detection.

Fig. 7, Fig. 8 and Fig. 9 show the spectra obtained with 241Am, 133Ba and 137Cs sources both, experimental and simulated by MCNP-X, normalized and denormalized.

We observe that the parameters found for the GEB function provided na spectrum that matches the experimental and, the methodology employed gives good results in the photopeak region, which is the region of interest in many studies.

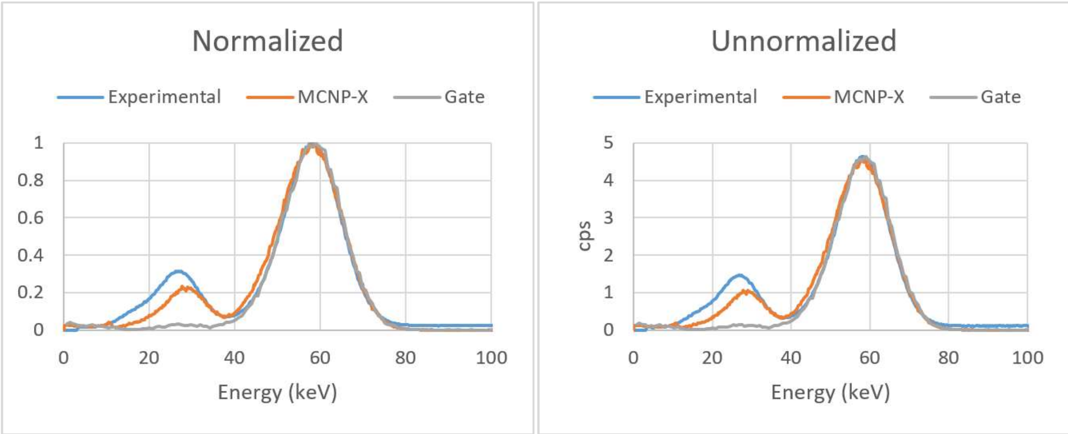

Figure 7: ^{241}Am spectra.

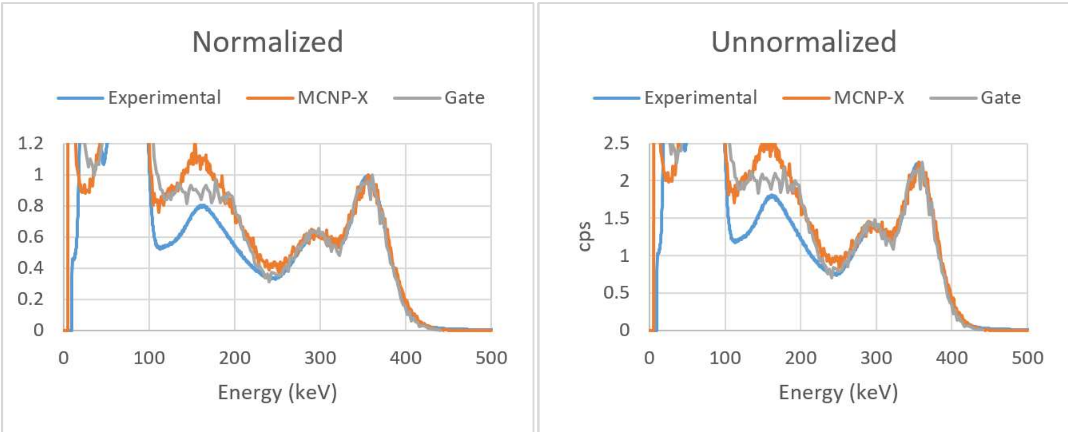

Figure 8: ^{133}Ba spectra.

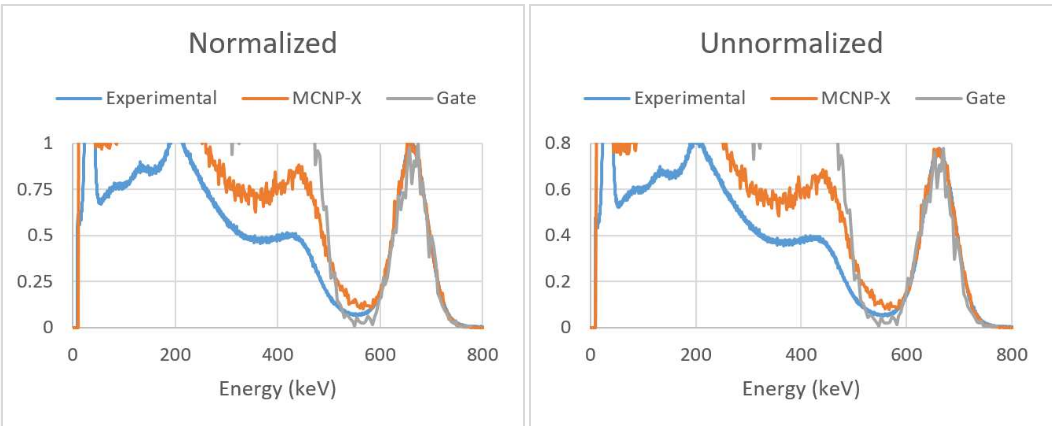

Figure 9: 137Cs spectra.

In studies of void fraction, in stratified regime, spectra with water level of 25%, 50%, 75% and 100% in relation to the pipe's diameter were obtained. The value of CPSe was obtained with the 25% level. The value of CPSs, was obtained by simulation of the same fluid level.

Fig. 10 illustrates the simulated spectra compared to the experimental spectra. Again, we observe that the methodology works well in the photopeak region.

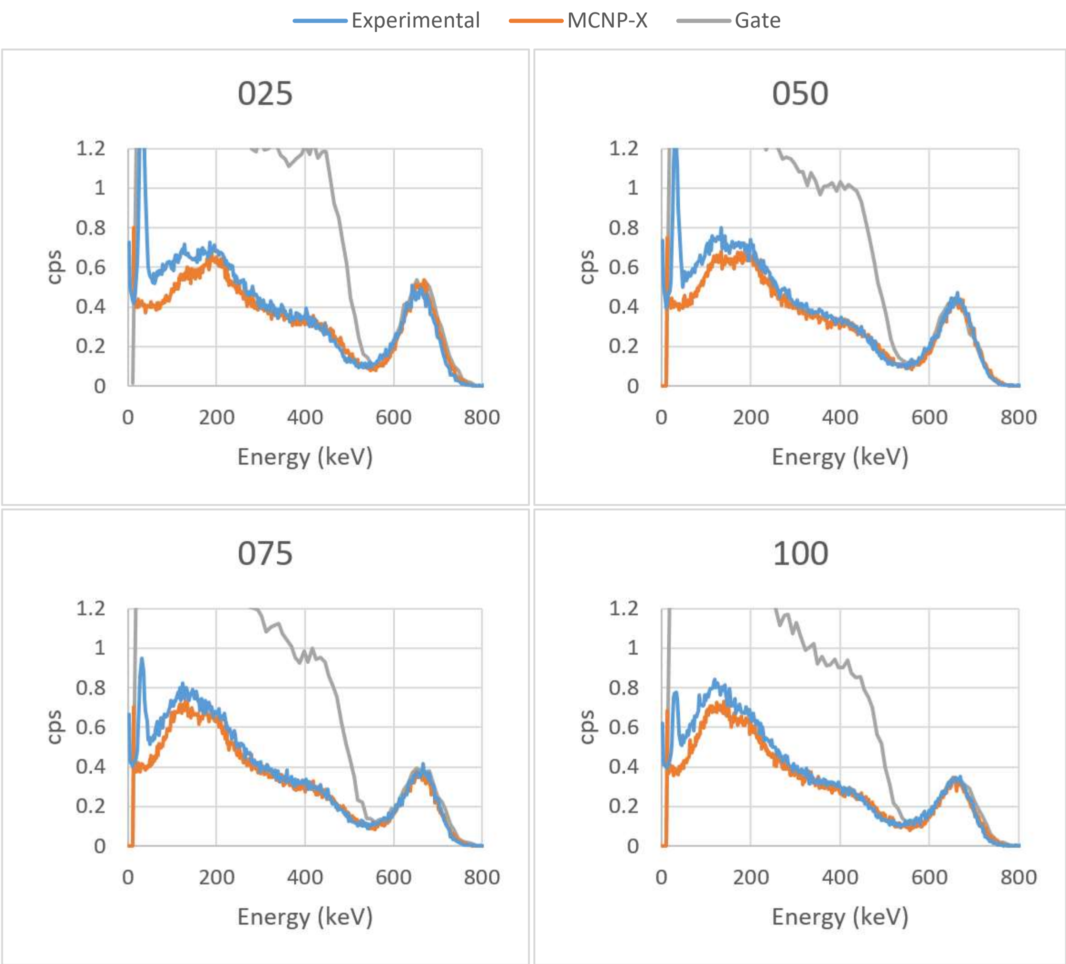

Figure 10: Comparison between experimental and simulated spectra.

5. CONCLUSIONS

The use of MCNP-X and Gate codes is extremely important, since, once the model is validated, an experimental arrangement is no longer needed, eliminating problems such as detector availability, radiation source availability, and experimental tests, among others during the initial stage of a project. In addition, it facilitates the construction of geometries, use of several detectors and energies, which can help determining the best configuration for a project.

In this context, we verified the need of creating a new methodology, meeting some parameters, to validate detector modeling.

The methodology developed in this paper proved to be simple and efficient for such validation. It is noteworthy its efficiency in studies of void fraction, contributing to the state-of-the-art of two-phase flow studies.

6. REFERENCES

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